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Optimal management of hereditary hemorrhagic telangiectasia

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Abstract: Hereditary hemorrhagic telangiectasia (HHT), also known by the eponym Osler–Weber–Rendu syndrome, is a group of related disorders inherited in an autosomal dominant fashion and characterized by the development of arteriovenous malformations (AVM) in the skin, mucous membranes, and/or internal organs such as brain, lungs, and liver. Its prevalence is currently estimated at one in 5,000 to 8,000. Most cases are due to mutations in the *endoglin* (*HHT1*) or *ACVRLK1* (*HHT2*) genes. Telangiectasias in nasal and gastrointestinal mucosa generally present with recurrent/chronic bleeding and iron deficiency anemia. Larger AVMs occur in lungs (~40%–60% of affected individuals), liver (~40%–70%), brain (~10%), and spine (~1%). Due to the devastating and potentially fatal complications of some of these lesions (for example, strokes and brain abscesses with pulmonary AVMs), presymptomatic screening and treatment are of utmost importance. However, due to the rarity of this condition, many providers lack an appreciation for the whole gamut of its manifestations and complications, age-dependent penetrance, and marked intrafamilial variation. As a result, HHT remains frequently underdiagnosed and many families do not receive the appropriate screening and treatments. This article provides an overview of the clinical features of HHT, discusses the clinical and genetic diagnostic strategies, and presents an up-to-date review of literature and detailed considerations regarding screening for visceral AVMs, preventive modalities, and treatment options.

Keywords: arteriovenous malformations, epistaxis, bevacizumab, embolization, guidelines, screening, review

Introduction

Hereditary hemorrhagic telangiectasia (HHT), also known by the eponym Osler–Weber–Rendu disease is a group of autosomal dominant disorders characterized by presence of multiple arteriovenous malformations (AVMs) in the skin, mucous membranes, and frequently internal organs such as lungs, liver, and brain. Current prevalence is estimated between one in 5,000 to 8,000. While this is thought to affect people of all races in all parts of the world, higher prevalence has been reported in specific populations, for example, one in 1,330 in Afro-Caribbean residents of Curaçao and Bonaire.^{1–3}

AVMs in HHT are characterized by lack of intervening capillaries between arteries and veins. Small AVMs known as telangiectasias are pink to red lesions, typically 0.5–1.0 mm in diameter. They may occur anywhere in the body but are most apparent on the lips, tongue, face, fingertips, and the nasal, buccal, and gastrointestinal (GI) mucosa. Unlike petechiae, which have a similar appearance, they blanch with pressure and refill immediately after the pressure is released. Due to their thin walls and

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proximity to the skin or mucosal surfaces, they are prone to rupture and bleeding with minimal injury. Epistaxis and mucocutaneous telangiectasias are the most common clinical manifestations.^{3,4} HHT is also often complicated by the presence of larger AVMs, also referred to as arteriovenous shunts or fistulae. These can be up to several centimeters in size and are most frequently observed in the lungs, liver, and brain. While these can rupture, complications from these larger AVMs are more often a result of shunting of blood. Involvement of systemic vasculature, for example in the liver, leads to a high cardiac output state. Pulmonary AVMs (PAVMs) serve as right-to-left shunts that lead to hypoxemia or neurologic sequelae due to paradoxical embolism of crural or septic thrombi. It should be noted that these vascular malformations can occur in disorders besides HHT, in isolation, and as part of another syndrome, and their presence is not adequate to arrive at this diagnosis.

Since HHT affects multiple organ systems, it does not “belong to” any one subspecialty; a wide range of physicians from medical, surgical, primary care, or emergency medicine disciplines may encounter affected patients. Given the rarity of this condition, physicians may lack appreciation of its full range of manifestations and complications, resulting in missed diagnoses or significant delays before the diagnosis is established.^{5,6} Furthermore, due to the catastrophic nature of some of the lesions seen in this syndrome (for example, strokes and cerebral abscesses from pulmonary AVMs), screening in the presymptomatic phase is extremely important. However, many patients and families remain unaware of their diagnosis and do not receive appropriate screening and preventive treatment.⁷ To bridge these gaps in care for patients with HHT and their families, a group of international experts met in Canada in 2006 and formulated the “International Guidelines for Diagnosis and Management of HHT” that were published in 2011.⁸

Here, we provide a brief overview of the clinical manifestations in HHT, an up-to-date review of diagnostic criteria for HHT, guidelines regarding screening in asymptomatic subjects with definite or likely HHT, and optimal management of various complications. We will also discuss the literature that has become available since October 2006, when the guidelines for HHT were initially formulated. In particular, there has been much enthusiasm around the use of the vascular endothelial growth factor (VEGF) antagonist bevacizumab; it has been shown to decrease severity of epistaxis as well as reduce liver size and cardiac output in patients with large hepatic AVMs (HAVMs). Lastly, we will discuss the implications of this diagnosis in special circumstances, such as pregnancy and when anticoagulation is required.

Clinical overview

Age-related penetrance is observed in HHT. Manifestations are rarely present at birth, but develop and worsen with increasing age. Individual signs and symptoms are discussed below.

Epistaxis

Nasal bleeding is the clinical characteristic that most commonly brings patients with HHT to medical attention. In a series of 324 patients with HHT, epistaxis was reported by 96% with over half experiencing this symptom before the age of 20 years.⁴ In another survey of 73 patients, 93% reported epistaxis, with onset before the age of 10 years in over 50% and before the age of 20 years in over 90%; the mean frequency of nosebleeds was 18 per month.⁹ It is an early and clinically evident marker of disease. Occasionally, it can lead to chronic anemia and transfusion dependence.

Mucocutaneous telangiectasias

Telangiectasias typically seen on the lips, tongue, buccal mucosa, and fingertips have been reported in 75%–90% of the affected individuals.^{4,10} They are usually recognized at a much later age than epistaxis, likely due to the relatively subtle and nonspecific nature of these lesions. They rarely bleed and the main concern is usually cosmetic. There are rare case reports of vocal cord involvement manifesting as dysphonia.¹¹

Gastrointestinal bleeding

Although 75% of the patients have gastric or small intestinal telangiectasias on endoscopy or capsule examination, only one-third eventually suffer from GI bleeding, usually after 40 years of age.^{4,12–14} Telangiectasias can occur throughout the GI tract, but are almost always more common in the stomach and duodenum. Bleeding is often slow and chronic, and may be clinically silent with no obvious melena. Symptoms may be completely absent until anemia develops. Larger AVMs or aneurysms are less commonly observed.

Pulmonary AVMs

PAVMs are more common in the general population than previously appreciated. Small pulmonary shunts are evident on transthoracic contrast echocardiography (TTCE) in 6%–7% of the individuals without HHT.^{15,16} In a recent study from Japan, PAVMs were identified in eight patients (0.038%) among 21,235 patients who underwent low-dose computed tomography (CT) screening for lung cancer.¹⁷ While only two patients were diagnosed with HHT in this series, other studies have shown that approximately 80%–90% of the

patients with PAVMs have underlying HHT.^{18,19} On the other hand, depending on the imaging technique used, PAVMs are identified in 40%–60% of patients with an underlying diagnosis of HHT.^{20,21}

PAVMs can lead to symptoms by causing complications such as systemic hypoxemia, pulmonary embolism, high output heart failure, or pulmonary hypertension. Symptoms may also manifest as a result of PAVM rupture. Dyspnea (that is sometimes noticeable only with exertion) is the most common symptom attributable to hypoxemia resulting from right-to-left shunting of blood, especially if the PAVMs are large, multiple, or bilateral.^{22,23} This, over time may lead to clubbing and compensatory polycythemia.²⁴ Acute postural change to standing can increase shunting of blood through PAVMs located at the base of the lung, resulting in orthodeoxia. In a series of 257 patients with PAVMs, 29% demonstrated a fall in blood oxygen saturation of at least 2% with standing.²⁵ Although platypnea accompanying this orthodeoxia has been reported in the literature, none of the patients in this large series reported dyspnea with standing.²⁶ Positional oximetry, although not very sensitive, is highly specific for PAVMs and should be a part of initial evaluation in patients with definite or suspected HHT.^{25,27} Additionally, due to lack of a capillary filter between arterial and venous beds, these patients are at risk for paradoxical embolism of *de novo* in situ cruoric thrombi or cruoric thrombi/septic thrombi/air emboli developing upstream. These result in embolic cerebral events, including embolic strokes and cerebral abscesses. In one series of 76 patients undergoing embolotherapy, symptomatic strokes were reported in 18%, transient ischemic attacks in 37%, and brain abscesses in 9%.²⁸ Notably, CT imaging of 59 patients in this series showed unequivocal evidence of stroke in 36%; cerebral AVMs (CAVMs) were documented in only 5%. Morbidity and mortality attributable to these catastrophic events is significant, hence the need for early screening and timely interventions (for example, embolization of PAVMs and antibiotic prophylaxis prior to dental procedures). Furthermore, high cardiac output state resulting from right-to-left shunting can over time lead to heart failure and/or pulmonary hypertension. According to a study of 1,143 patients undergoing PAVM embolization, the mean pulmonary arterial pressure was >20 mmHg in 9% of the patients and >25 mmHg in 6%.²⁹ Lastly, PAVM rupture can result as a complication of pregnancy, pulmonary hypertension, or in the presence of high-pressure systemic blood supply via bronchial circulation; this may present as hemoptysis and/or hemothorax.^{30–33}

Migraines are remarkably frequent in HHT patients with PAVMs, and there is evidence to suggest that embolization of PAVMs leads to symptom improvement.^{34–36} This association may be explained by passage of microthrombi and/or vasoactive substances (eg, serotonin) from the venous system to the cerebral circulation via PAVMs, or systemic hypoxemia.³⁷ That being said, migraines are still more common in HHT patients without PAVMs than in the general population.³⁸ A recent study by Elphick and Shovlin identified an especially strong association between epistaxis and migraines in HHT, suggesting common pathophysiologic mechanisms underlying both these manifestations.³⁹

CAVMs

CAVMs affect approximately 10% of HHT patients.^{40–43} These include, in order of decreasing size, arteriovenous fistulae, classical nidal AVMs, micro-AVMs (<1 cm), and telangiectasias. Due to the potentially devastating effects of cerebral hemorrhage, symptoms suggestive of CAVMs should be investigated with magnetic resonance imaging (MRI). However, most CAVMs never bleed and complications associated with currently available diagnostic modalities are substantial. Furthermore, recent evidence for patients with sporadic CAVMs suggests that the risk of stroke or death with interventional management is significantly higher than with medical management.⁴⁴ As such, the screening strategy needs to be individualized for each patient after careful discussion. It should be emphasized that most neurological events in HHT are a consequence of paradoxical embolism of clots and bacteria via PAVMs to the central nervous system, and CAVMs are detected in a small minority of the patients with definite evidence of stroke on CT imaging.²⁸

In infants and young children, large-caliber high-flow fistulae are more common and may present with intracranial bleeds, hydrocephalus, epilepsy, cognitive deficits, or high-output cardiac failure.^{41,45–49} Spinal AVMs are substantially less frequent (affect 1%–2% of the HHT population), and usually present early in childhood with paralysis and/or complaint of back pain.^{45,50,51}

HAVMs

Hepatic involvement is reported in up to three-quarters of patients with HHT, depending on the imaging technique used. In one series of 70 patients, HAVMs were detected in 74% using helical CT imaging; these led to symptoms in only 8% of these patients.⁵² In another series using ultrasonography, only 41% of the individuals with HHT were found to have

HAVMs.⁵³ In a study of 154 patients with HHT and HAVMs followed over a median period of 44 months, one-quarter experienced complications related to these AVMs and 5% died from their complications.⁵⁴

The vascular supply of the liver is unique. Blood enters through the hepatic artery and portal vein, combines in the hepatic sinusoids and exits via the hepatic veins. Clinical manifestations depend on the direction of shunts. The most common presentation related to HAVMs in HHT is a hyperdynamic circulatory state resulting from left-to-right shunting from the hepatic artery or portal vein to the hepatic veins.⁵⁵ Hepatomegaly and hepatic bruits may be appreciable on physical examination. These, over time, can lead to cardiac failure often presenting with dyspnea and dependent edema. Shunting of blood from the hepatic artery to the portal vein is less commonly observed. In this scenario, increased sinusoidal blood flow is associated with nodular transformation in the liver, also known as “pseudocirrhosis” and “arterialization” of the portal vein.^{56,57} The peribiliary plexus arising from the hepatic artery supplies blood to the biliary tree. Shunting of blood away from the hepatic artery to hepatic and/or portal veins may also cause ischemia of the intrahepatic or extrahepatic biliary systems, manifestations of which include severe cholestasis, recurrent cholangitis, and biliary strictures.

Juvenile polyposis

Individuals with juvenile polyposis-HHT overlap syndrome (JPHT) with mutations in *Smad4* gene (see “Molecular diagnosis” section) represent 1%–2% of the total HHT population. These patients are at increased risk for colorectal cancer and require close surveillance. More recently, connective tissue defects such as enlarged aortic root, valvular insufficiency, and aortic dissection have been described as well.^{58,59}

Venous thromboembolism

HHT patients carry a higher risk for venous thromboembolism (VTE) as compared to the general population.⁶⁰ Although the precise reason(s) for this are unknown, one recent study of 609 HHT patients identified an association of deficient iron stores with high coagulation factor VIII levels and increased thromboembolic risk.⁶¹ Given the predisposition for bleeding, anticoagulation presents an obvious challenge in this group and is discussed separately in detail.⁶²

Immunological abnormalities

In a retrospective analysis of 353 patients with HHT, 13.6% were identified to have severe infections.⁶³ Cerebral infections

accounted for one-third of all infections and were associated with the presence of PAVMs. The remaining two-thirds were extracerebral, most involved *Staphylococcus aureus*, and were attributed to epistaxis and need for prolonged nasal packing. In addition to these mechanical factors, defects in adaptive immunity (such as T cell and NK cell lymphopenia, increased levels of immunoglobulins G and A, and low levels of immunoglobulin M) have recently been identified in HHT.⁶⁴

Malignancy risk

A prospective study in patients with over 20 years of follow-up reported increased mortality attributable to complications of HHT in patients younger than 60 years; however, mortality in individuals older than 60 years was not increased.² Hosman et al evaluated this discrepancy and found that certain malignancies with especially poor prognosis, such as lung and liver cancers are less prevalent in HHT and could account for the better than expected life expectancy in older individuals within this population. Additionally, a modest increase in breast cancer prevalence was found, possibly related to recurrent exposure to ionizing radiation with CT and angiographic studies.⁶⁵

Diagnostic approaches

Clinical diagnosis

Establishing a diagnosis of HHT is imperative for patients and their family members for them to receive the appropriate screening and preventive treatments. This diagnosis has conventionally been based on clinical grounds. Consensus clinical diagnostic criteria known as Curaçao criteria were published in 2000; they remain the mainstay of clinical diagnosis to date (Table 1).⁶⁶

van Gent et al recently demonstrated excellent diagnostic performance for these criteria in 263 first-degree relatives of

Table 1 Curaçao criteria for clinical diagnosis of HHT

Criteria	
Epistaxis	Spontaneous and recurrent
Telangiectasia	Multiple, at characteristic sites: lips, oral cavity, fingers, and nose
Visceral lesions	Such as gastrointestinal telangiectasia, or pulmonary, hepatic, cerebra, or spinal AVMs
Family history	A first-degree relative with HHT according to these criteria
HHT diagnosis is	
Definite	If three or more criteria are present
Possible or suspected	If two criteria are present
Unlikely	If fewer than two criteria are present

Abbreviations: AVM, arteriovenous malformations; HHT, hereditary hemorrhagic telangiectasia.

disease-causing mutation carriers.⁶⁷ Among the 186 relatives with family-specific mutations, clinical diagnosis was “definite”, “possible”, and “unlikely” in 160 (90.3%), 17 (9.1%), and one (0.5%), respectively. Among the remaining 77 family members lacking the mutation, clinical diagnosis was definite, possible, and unlikely in zero, 35 (45.5%), and 42 (54.5%), respectively. As such, the positive predictive value of a definite diagnosis was 100% and the negative predictive value of an unlikely diagnosis was 97.7%. A few notes of caution regarding employment of these criteria are worth mentioning. First, as highlighted by Govani and Shovlin, they can prove inadequate when members of a family with HHT are encountered. In an individual with positive family history and confirmed PAVM(s), the diagnosis of HHT is effectively confirmed, even though these criteria label the diagnosis as “possible” or “suspected”.⁶⁸ At the same time, these criteria do not specify what counts as a PAVM. Using chest CT as the reference, TTCE (which is now recommended as the first-line examination for PAVM screening) has excellent sensitivity and negative predictive value, but lacks specificity and positive predictive value for detection of PAVMs.^{15,69} Velthuis et al evaluated the utility of TTCE results in establishing the diagnosis of HHT. They showed that addition of any pulmonary shunt on TTCE to the current Curaçao criteria resulted in increased sensitivity from 88% to 94%, but decreased specificity from 74% to 70%. Excluding grade 1 on TTCE as a diagnostic criterion for HHT enhanced the sensitivity to 90%, with no decrease in specificity.¹⁵ Secondly, as clinical manifestations of HHT develop with age, these criteria lack sensitivity and have limited value in children and young adults with positive family history but no other clinical manifestations. Genetic testing is required in these cases (see “Molecular diagnosis”). As commented upon in the “International Guidelines for Diagnosis and Management of HHT”, these criteria are particularly helpful in two situations:⁸ 1) discriminating affected from non-affected older adults and 2) ruling in the diagnosis in younger adults and children.

Molecular diagnosis

HHT follows an autosomal dominant pattern of inheritance; sporadic mutations leading to this syndrome are rare. Based on underlying genetic defects, five different types of HHT have been described thus far:

1. HHT type 1 results from mutations in the *endoglin* gene (*ENG*, *HHT1*; OMIM#187300).
2. HHT type 2 results from mutations in the *activin receptor-like kinase 1* gene (*ACVRLK1*, *HHT2*; OMIM 600376).

Four hundred and seventy variants in *ENG* and 375 variants in *ACVRLK1* have been described thus far; these account for approximately 87% of the cases.⁷⁰

3. JPHT: If testing for *ENG* and *ACVRLK1* is negative, sequencing of *Smad4* gene (*SMAD4*, *MADH4*; OMIM 175050) identifies mutations in an additional 1%–2% of individuals.^{71–75}

These three genes code for proteins in the transforming growth factor-beta (TGF- β) signaling pathway. The exact mechanisms by which these genetic defects influence the process of angiogenesis are not clear; they likely disturb the balance between proangiogenic and antiangiogenic signals in the blood vessels, in favor of the former. As a result, normal angiogenic stimuli lead to the development of AVMs with increasing age.

4. HHT type 3 is associated with mutations in locus 5q31.3-q32 (OMIM#601101).⁷⁶
5. HHT type 4 is linked to mutations at location 7p14 (OMIM#610655).⁷⁷

Specific genes at these two loci have not yet been identified, and the mechanisms by which they lead to HHT are not known.

6. More recently, mutations in the growth differentiation factor 2 gene (*GDR-2*, *BMP-9*, *HHT5*; OMIM 615506) that are involved in angiogenesis were described in three individuals with a vascular-anomaly syndrome that has phenotypic similarities with HHT.⁷⁸

For patients with “definite” clinical diagnosis, genetic testing is not required to confirm their diagnosis. The objective of genetic testing is often to identify the specific mutation in the index case. Once this family specific mutation is identified, targeted sequencing can be valuable in two settings: 1) to effectively establish the diagnosis in relatives of individuals with HHT who do not (yet) meet clinical diagnostic criteria, particularly in children and young adults, and 2) more commonly, to rule out the diagnosis in a branch of the family.

A directory of laboratories across the world that offer genetic testing for HHT is available on the HHT Foundation International website.⁷⁹ A few caveats about diagnostic usage of genetic testing are noteworthy:

- Mutations have not been identified in 15%–20% of HHT families.^{80–82} In the appropriate clinical context, negative testing in the index patient does not change his/her diagnosis and management. However, this does limit being able to use targeted genetic testing to rule in or rule out the diagnosis in other family members.⁸
- Ten to twenty percent of the families have genetic variants (usually potential missense mutations), pathogenicity of

which are not clear; this can lead to overdiagnosis. This will likely become an even bigger problem as newer sequencing technologies are applied to promoter and intronic sequences of HHT genes.^{80,83,84}

- PAVMs and CAVMs are more common in HHT type 1, HAVMs and pulmonary arterial hypertension are observed more often in HHT type 2, and most studies have showed no significant differences in the prevalence of GI bleeding between the two HHT types.^{10,80,85–90} Nevertheless, all of these features are seen in both types. Knowing the underlying mutation does not alter the screening or management strategy for an individual patient. The only exception to this is patients with JPHT; they require regular colonic surveillance for GI malignancies beginning at an early age.^{74,75,91}

Management

In a patient with “possible” and “definite” HHT, optimal management includes: 1) treatment directed towards organ-specific signs and symptoms; 2) screening and subsequent management of PAVMs and sometimes CAVMs while in the asymptomatic phase, given the disastrous and potentially fatal complications associated with them; and 3) education, with opportunity for genetic testing in index patients and in at-risk family members, whenever possible (see “Molecular diagnosis”). It should be noted that most of the current guiding principles are based on expert opinion, there are very few randomized controlled trials addressing different therapies in HHT.⁸

Epistaxis

Severe epistaxis has been repeatedly found to be the most significant clinical variable associated with poor quality of life among HHT patients.^{92–94} Treatment can be difficult and frustrating, both for the patient and providers. Modus operandi for these patients should include systematic evaluation of severity of nosebleeds, a stepwise treatment approach (including correction of anemia and iron deficiency), and regular follow-up. Hoag et al described a statistically validated epistaxis severity score (ESS) that can serve as a useful adjunct in clinical evaluation and follow-up of HHT patients.⁹⁵ Given the unique characteristics of this disorder and nuances of its management, referral to an otorhinolaryngologist with expertise in HHT-related epistaxis, whenever possible, is recommended. A list of HHT treatment centers is available online at the HHT Foundation’s website (<http://www.hht.org/living-with-hht/treatment-centers-2/>). Various treatment options are discussed next:

- Air humidification and regular application of lubricants such as saline (to prevent crusting over nasal mucosa) and avoidance of injury to nasal mucosa (for example, with picking and blowing hard) are generally recommended for management of chronic and recurrent nosebleeds.⁹⁶ Certain dietary ingredients have been reported to exacerbate nosebleeds; these include foods with high salicylate content (such as red wine, spices, chocolate, and coffee), with natural antiplatelet activity (such as ginger, garlic, ginkgo biloba, and ginseng), and with high levels of omega-3 acids (such as salmon).^{39,96} Identification of patient-specific triggers and their avoidance may aid with epistaxis management.
- Surgical options:
 - Nasal packing is often the first-line of management for acute bleeding. Use of pneumatic packing minimizes re-bleeding after removal of packing material.
 - Laser coagulation is recommended as a low-risk intervention for management of mild-to-moderate epistaxis.^{97,98} This is considered to be preferable to electrical and chemical cautery as it causes less damage to nasal mucosa, which would further worsen bleeding.
 - For severe epistaxis that does not respond to repeated endonasal coagulation, septal dermoplasty has been shown to be effective in reducing transfusion requirements and improving quality of life measures.⁹⁹ Alternatively, Young’s nasal closure procedure (in which the nostrils are sewn closed so a person no longer breathes through the nose) usually leads to complete cessation of bleeding; patient often report side effects of chronic mouth breathing including alterations in smell and taste senses.^{100,101} In a recent series of 43 patients undergoing this procedure, nosebleeds stopped completely in 83% of the patients and a mean increase in hemoglobin of 4.68 g/dL was observed.¹⁰²
 - Nasal arterial embolization is effective only in the short term, as surrounding blood vessels enlarge and lead to recurrence of bleeding. This should be reserved only for emergent management only, until more durable therapies can be started.
 - Submucosal radiofrequency has recently been shown to be safe and efficacious as a therapy for epistaxis in HHT, although long-term effects remain to be evaluated.¹⁰³
- Medical options: Various medical treatments (antiangiogenic, hormonal, and antifibrinolytic) have been reported for management of HHT-related epistaxis.

- Angiogenesis inhibitors: VEGF levels have been shown to be about 15-fold elevated in patients with HHT and are implicated in its pathogenesis.¹⁰⁴ Bevacizumab is a recombinant humanized monoclonal antibody that binds to VEGF receptors on endothelial cells and serves as a competitive antagonist. In HHT, its systemic administration has been shown to improve HAVM-related symptoms as well as epistaxis.¹⁰⁵ Several uncontrolled series reported efficacy and safety of local administration of bevacizumab in HHT-related epistaxis.^{106–111} In one recent double-blind, placebo-controlled trial, 15 adult HHT patients with a minimum of two epistaxis episodes per week were randomized to a single intranasal submucosal injection of 100 mg bevacizumab or placebo.¹¹² The average daily posttreatment visual analog score decreased by 27% in the bevacizumab group and by only 3% in the placebo group ($P=0.57$). In another Phase I, randomized, double-blind, placebo-controlled study (ELLIPSE trial) of 40 patients, five increasing doses (12.5, 25, 50, 75, and 100 mg) of bevacizumab nasal spray were evaluated.¹¹³ The drug was well-tolerated in all patients and was not detected in their serum; however, no efficacy was observed at any dose. A Phase II study is needed to determine the effectiveness of the drug. In summary, bevacizumab represents a promising therapy for management of HHT-related epistaxis. The cost and systemic side-effect profile of this drug (hypertension, increased bleeding risk, increased thromboembolic risk, proteinuria, and less frequently, renal thrombotic microangiopathy, bowel perforation, and nasal septum perforation) are not negligible; however, the adverse effects are largely avoided with topical use.

Anecdotal positive reports of thalidomide, another antiangiogenic agent have also been presented.^{114,115} However, there have been no controlled trials using this drug. Additionally, nonselective beta-blockers such as propranolol and timolol may have some antiangiogenic properties as well (related to vasoconstriction and reduced VEGF expression). They have been documented to be effective in the treatment of infantile hemangiomas, and may be a potential therapeutic option for HHT in future.^{116–118}
- Hormonal and antihormonal therapies: Combined estrogen–progesterone at doses used for oral contraception may eliminate bleeding in symptomatic HHT and could represent a reasonable option for women of childbearing age.¹¹⁹ Similarly, selective estrogen

receptor modulators such as tamoxifen and raloxifene may have a role in management of HHT-related epistaxis in postmenopausal women.^{120–122} Yaniv et al reported a trial where 25 patients with HHT-related epistaxis were randomly assigned to receive oral tamoxifen 20 mg/day or placebo for 6 months. Among the 21 participants who completed the trial, nine out of ten tamoxifen-treated patients reported alleviation in the frequency and severity of their nosebleeds, as opposed to only three out of eleven in the placebo arm.¹²¹ Beneficial side effects of tamoxifen include prevention of bone loss and improvement in serum lipid profile. In addition to unpleasant effects resulting from its antiestrogenic properties (mood changes, hot flashes, etc), the most concerning adverse effect is the increased incidence of uterine malignancies.

- Antifibrinolytics: A recent randomized, double-blind and placebo-controlled trial of tranexamic acid demonstrated a 50% decrease in nosebleeds; however, no significant improvement in the primary outcome, ie, blood hemoglobin concentration was observed.¹²³ Aminocaproic acid has also been reported to decrease epistaxis severity.¹²⁴
- Antioxidants such as N-acetyl cysteine (NAC) have also been evaluated in the treatment of epistaxis. In an observational study, 43 patients taking NAC 600 mg thrice daily for 12 weeks reported a decrease in the frequency and severity of diurnal nosebleeds.¹²⁵

GI bleeding and malignancies

Management in these patients usually focuses on early detection and treatment of anemia and underlying iron deficiency.

Because of increased risk of GI bleeding with age, annual measurement of hemoglobin or hematocrit and serum iron studies beginning at 35 years of age is recommended.⁸ Direct endoscopic evaluation should be performed only if anemia is present and is disproportionate to the amount of epistaxis. Fecal occult blood testing can be falsely positive due to swallowed blood from nosebleeds, and hence, is less useful as a screening. As noted earlier, based on our current knowledge, JPHT represents the only subtype where the screening strategy is affected by the underlying genotype. Juvenile polyposis in these patients places them at increased risk for colonic malignancies. Screening colonoscopies starting at 15–18 years of age or at an age 5 years younger than at which the youngest family member developed colon cancer, whichever is earlier, and every 2 years thereafter, are recommended.⁹¹

Since most bleeding occurs in the stomach and duodenum, an upper esophagogastroduodenoscopy (EGD) is usually adequate to make the diagnosis. However, presence of telangiectasia does not rule out other sources of bleeding or anemia (for instance, epistaxis) in these patients. If upper and lower endoscopies do not adequately explain the severity of findings, or in patients where numerous lesions are expected (HHT type 1, older age, or severe anemia in the setting of limited epistaxis), video capsule endoscopy may be considered as the initial step as it provides better information about the distal part of the duodenum and small intestine.⁸⁹ Iron absorption and handling are preserved in HHT, and the iron deficiency is explained by the losses due to chronic bleeding.¹²⁶ Aggressive and long-term iron replacement is often required for maintenance of iron stores and to minimize the need for blood transfusions. Oral iron supplements should be attempted before switching to intravenous preparations. Evidence for use of different medical therapies to reduce chronic GI bleeding (estrogen–progesterone preparations, danazol, tamoxifen, thalidomide, lenalidomide, interferon, sirolimus, and bevacizumab) is limited to case reports and small case series.^{13,124,127–134} There is one small double-blind, placebo-controlled, cross-over trial of combination hormonal therapy (0.05 mg ethinyl estradiol plus 1 mg norethisterone) versus placebo; five of the six HHT patients experienced no further GI bleeding.¹³⁵ Limited attempts at cauterization of large visible telangiectasias by an experienced endoscopist may be considered; however, repeated endoscopic attempts are unlikely to be effective.^{136–138}

PAVMs

Neurological complications resulting from PAVMs are a significant cause of morbidity and mortality among HHT patients.^{43,139,140} Screening for PAVMs is recommended in all patients with possible or definite HHT at the time of initial evaluation, regardless of age.^{8,141}

TTCE, also referred to as “bubble echocardiography” is recommended as the first step in screening for PAVMs. It is simple, minimally invasive, and does not require exposure to radiation. After intravenous injection of agitated saline solution, if a right-to-left pulmonary shunt is present, echoic microbubbles (referred to as contrast) can be easily visualized in the left cardiac cavities after 2–5 seconds or three to eight cardiac cycles (appearance of contrast in the left ventricle within one cycle of its appearance in the right atrium suggests an intracardiac right-to-left shunt). Depending on the extent of opacification of the left ventricle,

a semi-quantitative assessment of the shunt size can be obtained.¹⁴² These grades are:

1. Grade 0, no bubbles (no additional testing is required);
2. Grade 1, occasional filling with less than 30 bubbles;
3. Grade 3, moderate filling with 30–100 bubbles; and
4. Grade 4, complete opacification with more than 100 bubbles.

Multiple prospective studies have documented excellent sensitivity (97%–100%) and negative predictive value (99%–100%) of TTCE for detection of PAVMs, making it an excellent screening test.^{16,69} However, it lacks specificity (49%–77%) and the positive predictive value is low (32%–51%). Additionally, as noted earlier, a study by Velthuis et al showed limited diagnostic significance of grade 1 shunts detected by TTCE.¹⁵ A recent cross-sectional study by the same group that included over 1,000 patients with HHT showed that a pulmonary shunt grade 1 was not associated with increased prevalence of cerebral complications (odds ratio [OR]: 0.44; 95% confidence interval [CI]: 0.05–4.13; $P=0.47$), whereas pulmonary shunts grade 2 and grade 3 carried an OR of 4.78 (95% CI: 1.14–20.0; $P=0.03$) and 10.4 (95% CI: 2.4–45.3; $P=0.002$), respectively, for cerebral ischemic event or brain abscess.¹⁴³ Another analysis demonstrated that among 772 HHT patients, none of the 201 individuals with grade 1 TTCE results had PAVMs on chest CT that were amenable to embolization.¹⁴⁴ Based on these data and concerns about potential long-term effects of repeated exposure to radiation, it appears reasonable to state that CT can safely be withheld in asymptomatic individuals with grade 1 pulmonary shunt on TTCE.¹⁴⁵ On the other hand, follow-up imaging is definitely warranted in all patients with grade 2 and grade 3 results. Low-dose CT techniques allow an approximately 50% reduction in radiation dose without any significant difference in detection of abnormalities, and should be preferred over standard CT protocols.¹⁴⁵ Use of magnetic resonance angiography (MRA) has not been evaluated for PAVM screening; however, it may have a role in preembolization planning.¹⁴⁶ Its biggest advantage over CT is avoidance of ionizing radiation exposure.

Management of PAVMs is largely interventional. The “International Guidelines for Diagnosis and Management of HHT” recommended transcatheter embolization for PAVMs with feeding artery diameter greater than 2–3 mm.⁸ In 2008, Shovlin et al documented that the risk of cerebral events from PAVMs in HHT is independent of the feeding artery diameter; their study also demonstrated effectiveness of embolization in treating PAVMs in reducing strokes.¹⁴⁷ These data imply that all PAVMs, where embolization is considered

technically feasible and safe (irrespective of size), should be treated. Once the decision to proceed with embolization is made, a conventional diagnostic pulmonary angiogram is required to fully characterize the AVM, followed by catheter-directed placement of embolic material (such as metallic coils, detachable balloons, and Amplatzer vascular plugs) into the feeding artery until the blood flow through the PAVM stops. Whenever possible, both these steps should be done in the same session to minimize total radiation exposure. Amplatzer vascular plugs allow better management of larger AVMs, complex AVMs, and multiple AVMs in a single session and are being increasingly used.^{148–150} Various studies have documented safety and short- and long-term effectiveness of the procedure.^{18,148,149,151–154} Pleuritic chest pain, usually self-limited, is the most common complication. Recanalization of the occluded feeding artery was identified as the most common reason for treatment failure, often requiring reembolization.^{154,155} As a result, CT is recommended 3–6 months after the procedure, and then another 3 years later.¹⁵⁵ Recent evidence suggests that MRA may be a reasonable alternative to CT for follow-up examinations and detection of recanalization.¹⁵⁶ Of note, TTCE remains positive in ~90% of the patients despite complete occlusion of all angiographically visible PAVMs (likely reflective of other smaller PAVMs), and is not helpful in follow-up.¹⁵⁷

The role of surgery is limited to management of life-threatening hemorrhage from a ruptured AVM, when embolization is not available. Lung transplantation is occasionally pursued for patients who have diffuse bilateral disease refractory to all other treatment and are therefore at considerable risk for death from their underlying PAVMs.¹⁵⁸ There are no data regarding efficacy of any pharmacologic options discussed earlier in management of PAVMs.

Other measures that should be taken for prevention of complications related to PAVMs, treated or untreated, include:

1. Lifelong antibiotic prophylaxis: Strong association between oral microorganisms and brain abscesses in HHT is well-documented.¹⁴⁷ Antibiotic prophylaxis is recommended for all patients with PAVMs (treated or untreated) prior to procedures with risk of bacteremia, in particular dental procedures.¹⁵⁹
2. Careful precautions should be taken in these patients to avoid introduction of intravenous air during administration of intravenous medications.
3. Avoidance of scuba diving is generally recommended; however, the concern regarding increased risk of complications from decompression in patients with PAVMs

is only theoretical.⁸ Interestingly, with the exception of epistaxis, in-flight complications in patients with HHT are relatively uncommon.¹⁶⁰

CAVMs

Due to the debilitating and potentially fatal effects of CAVM rupture and the lack of evidence regarding effectiveness of treatment for asymptomatic CAVMs, the “International Guidelines for Diagnosis and Management of HHT” recommended screening for them in all patients (including children in the first 6 months of life) with possible or definite HHT.⁸ However, this has been a subject of significant debate for many reasons. First of all, most CAVMs never bleed. In fact, the bleeding risk of CAVMs associated with HHT (~0.5% per year) is much lower than with sporadic CAVMs (2%–4% per year).¹⁶¹ However, there remains concern regarding selection bias and survivor bias leading to better CAVM rupture rates in HHT. Secondly, the techniques employed for establishing the diagnosis carry more than minimal risk. While MRI itself poses minimal risk, sedation or anesthesia is often required in infants and children undergoing this procedure. Diagnostic angiography, which is the gold standard for diagnosis and required for treatment planning, is associated with a 0.5% risk of permanent stroke.¹⁶² Thirdly and most importantly, the evidence that has become available since 2006 when these guidelines were initially prepared suggests that the benefits of managing these CAVMs are outweighed by the risks of interventional therapies. In the ARUBA trial, where 223 patients with non-HHT-related CAVMs were randomized to interventional therapy vs medical management alone, the risk of stroke or death in the interventional arm was three-fold higher (30.7% vs 10.1%), warranting premature termination of the study.⁴⁴ Such studies evaluating the risk–benefit considerations have not been conducted in the HHT population (where the true incidence of CAVM rupture may be higher). Considering all these reasons, we suggest that instead of routinely screening all asymptomatic individuals with definite or possible HHT, the possibility that CAVMs will be identified in about 10% of the individuals with HHT and the concern that the risks of therapy may outweigh its benefits should be discussed explicitly with the patients and their families. The decision to proceed or not proceed with imaging should be made only after careful discussions. History of cerebral hemorrhage in a relative may be a considerable source of worry for the other family members with HHT. Whether the predisposition to cerebral hemorrhage related to CAVM is familial or related to a particular genotype is not known; however, a negative imaging study may help alleviate their

anxiety. Another scenario where this may be useful is prior to making a decision regarding initiation of anticoagulation (see “Antiplatelet therapy and anticoagulation”).

When the decision is made to proceed with screening or in patients with symptoms suggestive of CAVMs, brain MRI with and without contrast is the appropriate initial investigation.^{163–166} Angiography is required for confirmation of diagnosis and treatment planning. The size and number of lesions, venous drainage pattern, and involvement of the eloquent cortex determine the feasibility and risks of intervention (most importantly the risk of hemorrhage).¹⁶⁷ Referral to a center with expertise in managing these AVMs is recommended. Open microsurgical excision provides the best chance for cure. For lesions that are inoperable, stereotactic radiosurgery is another option; however, the cure rate is much lower and depends on the size of the AVM.¹⁶⁸ Unlike with PAVMs, embolization alone is rarely effective in the management of CAVMs but may be a useful adjunct to surgery or radiation therapy.¹⁶⁹

HAVMs

Screening for HAVMs in asymptomatic individuals is not done routinely, because 1) HAVMs are symptomatic in <10% of the cases; 2) when symptomatic, their presentation is not sudden and catastrophic (as with PAVMs and CAVMs); and 3) usefulness of treatment of asymptomatic lesions is not known. That said, screening for HAVMs can be used for clarification of diagnosis in patients meeting one or two Curaçao criteria. When screening is undertaken, it is advisable to start with Doppler ultrasound.^{8,170} It is accurate, noninvasive, highly available, and inexpensive.^{52,53,55,71,171–175} Multi-slice CT and MRI provide better characterization of hepatic lesions and may be considered if expertise in Doppler ultrasound for liver AVMs is not available. Mesenteric angiography is almost never required. Liver biopsy carries a high risk of hemorrhage in these patients and should be avoided.

High-output cardiac failure is treated with conventional medical therapy, including correction of anemia (often requiring blood transfusions), salt and fluid restriction, diuretics, and beta-blockers. Portal hypertension is managed according to present guidelines for cirrhotic patients with salt and fluid restriction and diuretics, therapeutic large-volume paracenteses with plasma expansion with albumin may be required.

Orthotopic liver transplantation (OLT) offers a definite cure.^{176–178} In the largest series of 40 HHT patients undergoing OLT, 17.5% patients died in the early postoperative period mainly due to bleeding complications; however, the actuarial 5- and 10-year survival rates were over 80%.¹⁷⁸ Interestingly,

two of these patients developed multiple recurrent AVMs in the graft 8 and 10 years later, possibly due to circulating proangiogenic factors. Given the significant risk from surgery and chronic immunosuppression, OLT is reserved for: 1) intractable heart failure, 2) intractable portal hypertension, and 3) ischemic biliary necrosis.⁸

Hepatic artery embolization frequently improves heart failure and portal hypertension; however, the benefit is usually transient and the rate of severe complications (hepatic necrosis, cholangitis, and cholecystitis) and death is extremely high.^{179–182} As a result, this procedure is limited to patients with intractable heart failure or portal hypertension who are not candidates for transplantation, after exclusion of those at extremely high risk for complications (ie, those with cirrhosis, severe biliary disease, or portovenous shunts).¹⁸³

Systemic bevacizumab is a promising therapeutic option for HAVMs. In a recent Phase II trial, 25 adult HHT patients with severe liver involvement and a high cardiac index were treated with bevacizumab (5 mg/kg every 14 days for a total of six injections).¹⁰⁵ Six-month follow-up data was available for 23 patients; it showed complete response (ie, normalization of cardiac index) in five cases and partial response in 15 cases. Blinded cardiac index at 6 months (mean 4.06 L/min/m²; 95% CI: 3.80–4.33) was significantly lower than at the beginning of treatment (mean 5.01 L/min/m²; 95% CI: 4.72–5.29). Hypertension and proteinuria are common side effects of this drug. Additionally, VEGF inhibition has been implicated in glomerular injury and development of a renal thrombotic microangiopathy, requiring withdrawal of treatment.¹⁸⁴ While OLT remains the therapeutic option of choice, bevacizumab may be useful as bridging therapy for patients who are awaiting transplantation or an alternative for patients who are not eligible for transplantation.

Special considerations

Pregnancy

Pregnancy in HHT is high risk. While a majority of women with HHT have an uneventful pregnancy, it is associated with an increased risk of life-threatening complications. In a study of 484 pregnancies in 199 women, 1.0% resulted in a major PAVM bleed, 1.2% in stroke, and 1.0% in maternal death.³⁰ Screening and management recommendations specific to pregnancy include:

- Ideally, PAVMs should be screened for and maximally treated prior to a planned pregnancy.⁸
- If a woman with HHT who has not had screening for PAVMs presents when she is already pregnant, screening should still be considered. A small series of seven patients

showed that transcatheter embolization by an experienced interventionalist, with modifications to minimize fetus exposure to radiation may be safely undertaken in the second and third trimesters.¹⁸⁵

- In a recent retrospective analysis, no increased risk of hemorrhage was found in patients with sporadic CAVMs during pregnancy and puerperium.¹⁸⁶ Given the low risk of bleeds and high risk of any interventional therapy, the role of screening (even in women with family history of cerebral hemorrhage) is unclear.
- Although frequently performed, current evidence does not support routine screening in all pregnant women with HHT for spinal AVMs prior to administration of epidural anesthesia. Spinal AVMs are rare, affecting only 1%–2% of the patients and usually present in early childhood.^{50,51} In one study, spinal or epidural anesthesia was used in 92 out of 185 deliveries in women with HHT, none of whom had undergone screening for spinal AVMs; no complications were observed.¹⁸⁷
- Parents should be made aware of the 50% likelihood of disease in the offspring. There is no evidence for or against antenatal testing for HHT at this time.

Antiplatelet therapy and anticoagulation

Patients with HHT (who carry an increased risk for VTE) are frequently advised to avoid antiplatelet therapy and anticoagulation.⁶² There are reports where withholding treatment for myocardial infarction due to diagnosis of HHT contributed to a patient's death; there are also reports where treatment for myocardial infarction led to hemorrhages and worsened outcomes.⁶² While epistaxis worsens with these therapies in about 60% of the patients, it is notable that nearly 40% report no change in the frequency or severity of nosebleeds.⁶² The side-effect profile with respect to bleeding associated with use of antiplatelet and anticoagulant therapies in this population is quite variable.¹⁸⁸ While data are limited to guide use of antiplatelet and anticoagulant therapies in individual patients, we want to emphasize that HHT by itself should not be considered an absolute contraindication. If faced with a compelling indication, these medications may be prescribed, at the lowest possible doses and with careful monitoring.

Radiation risk

HHT patients, particularly those with PAVMs, are repeatedly exposed to ionizing radiation from interventional procedures and CTs. In a recent analysis, 246 HHT patients with PAVMs underwent 3,309 procedures requiring ionizing radiation and cumulative effective dose exceeded 100 mSv (a level

at which there is considered to be good evidence for risk of significant harm) in 11%.¹⁴⁵ Physicians need to be cognizant of these risks. MRI or low-dose protocols for CTs definitely warrant consideration in patients who may be expected to undergo multiple procedures over the course of their lifetime, especially children.^{189–191}

Summary

Optimal management in HHT comprises:

1. Early diagnosis: The diagnosis of HHT typically relies on clinical findings. Genetic testing is not required to confirm the diagnosis in an individual case. However, if a family-specific pathogenic mutation is identified, it can be used to establish the diagnosis in other family members, particularly children and young adults who may not meet the clinical diagnostic criteria;
2. Screening for visceral AVMs: Decisions regarding screening and treatment of visceral AVMs (especially CAVMs) should be made after explicit and careful discussions with patients and their families, in view of their age, educational level, and cultural background;
3. Treatment of symptomatic and certain presymptomatic lesions such as PAVMs: Our understanding of the efficacy and safety of existing therapies in HHT is rapidly evolving and many new treatment options are becoming available. Whenever appropriate, patients should be encouraged to participate in research studies, and;
4. Education: Effective education and counseling of affected individuals regarding the implications of diagnosis of “possible” or “definite” HHT and the preventive and therapeutic options available for them is critical not only for their management, but also for identification of at-risk family members. Establishing a diagnosis in them while still in the presymptomatic phase can allow appropriate screening and treatment measures to be done in a timely manner.

Disclosure

The authors report no conflicts of interest in this work.

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